

SONAR SYSTEM ESPECIALLY FOR SHALLOW WATER APPLICATION SUCH AS IN LITTORAL ENVIRONMENTS

This application claims priority from U.S. Provisional Application No. 60-214,159, filed June 26, 2000.

Description

The present invention relates to sonar system useful for active submarine detection especially in shallow water littoral environments.

A system according to the invention uses a broadband source, such as a multiple pulse airgun array, whereby the broad transmitted bandwidth of, say, from below 50 to above 600 Hz can be processed simultaneously in a multiplicity of narrower sub-bands, to seek the maximum target return against propagation loss, noise and reverberation at any aspect the target chooses to present (or inadvertently presents) to the detection system (hydrophone array). The system may also use a broadband single transmission for use with broadband processing techniques to select a narrow band having maximum target return.

It is well known that the target strength of a submarine varies with submarine class, frequency and aspect. Furthermore, the propagation loss through the water varies with frequency, depth, and bottom composition. Additionally, reverberation caused by the surface and bottom structure can be a severe impediment to active submarine detection.

In light of the above many factors that can influence submarine detectability, there has arisen a school of thought that has focused on using broadband single-shot transmissions to blanket the frequency ranges that propagate well, to minimize reverberation through reduced "spot" size, and to use neural networks or other advanced processing means to recognize submarine target echoes from those of rocks and irregular bottom features. These steps have met with some success, but the reduction of reverberation and clutter, particularly, has been sufficiently limited in certain

instances to make it desirable to seek other (or additional) solutions. Reverberation encompasses acoustic reflections from the irregular structure of the water column due to temperature, salinity and current fluctuations. Clutter generally encompasses returns from irregular structure in the bottom including fluctuations in density, irregular rock formations, etc.

Reverberation and clutter have been addressed by transmitting a sequence of closely-spaced transmissions and matched-filter processing the returned signals. Such processing can provide 20 to 40 dB of reverberation/clutter suppression and contribute to the improved illumination of a moving target.

Although matched-filter processing can be done on a broad band basis, there is considerable advantage to restricting processing bandwidth to narrower (e.g., 50 Hz) bands which provide steeper slopes to the processed Q functions, allowing for the detection of slow moving targets, such as $\frac{1}{2}$ to 1 knot observed velocity with respect to the bottom.

For any broadband source (for example, an airgun array), a large number of multiple, narrow (e.g., 50 Hz) frequency bands are available for use, and, in principle, specific bands could be selected at any given time and location by the operator, based upon prior knowledge of the propagation characteristics of the particular region involved and/or the particular nature of the target being pursued. This approach, which depends on operator selection, while probably effective in some instances, may not be optimum. In general, it is unlikely that the operator can make the choice of the optimum sub-band in real time.

If the operator had a clue as to the aspect the target is presenting to him he could use information on target strength as a function of aspect, that can come from measurements and/or modeling of a scale model submarine of the design that is being pursued, to make a selection of "best" frequency band or bands.

However, the propagation loss between target and interrogating sonar can also fluctuate with frequency, sometimes exhibiting nulls. This fluctuation may defeat or compromise any effort to choose a frequency band based upon the suspected target aspect alone.

Of the many features that impact on target detectability, a feature that is generally under the control of the sonar operator is the frequency or frequency bands of the active transmission. In the case of a wide-band transmission (e.g., from the airgun source) usefully extending from, say, 50 Hz to 600 Hz, the question is, "Which sub-band or bands should be employed by the operator?"

The invention continually takes advantage of the full bandwidth capability of the airgun source and automates much of the submarine search process, to reduce decision making on the part of the operator and yet provide the operator with more information than has heretofore been available.

The invention provides a sonar system with novel signal processing of returns from a target which is interrogated by a broadband transmission. A multiplicity of contiguous narrow (e.g., 50 Hz) bands are match-filter processed in parallel to seek the frequency band giving, on a joint basis, the best contribution of target response and least propagation loss between target and interrogator.

Accordingly, a system provided by the invention is operative to examine, on each beam, all of the relatively narrow (e.g., 50 Hz) frequency bands simultaneously and to instruct the processor to select and exhibit the joint optimum responses for that beam. Each 50 Hz band between 50 Hz and 600 Hz (or other suitable overall band) can be examined in parallel for each beam. The question of which 50 Hz band or bands best present a target response is accommodated since all bands are being searched simultaneously and a computer-aided detection processor with appropriate training can make a detection decision based upon the best band response.

Figure 1 is a block diagram of a presently preferred signal processor of a sonar system in accordance with this invention. The matched-filter processor, shown in Figure 1, by exhibiting a target return having a non-zero velocity, also becomes a moving target classifier.

A broadband airgun system, such as described in Bouyoucos US Patent 5,995,452, issued Nov. 30, 1999 (hereby incorporated by this reference), can provide an unparalleled versatility and robustness. Its inherent broad bandwidth enables the Figure 1 matched-filter processor to expose the optimum detection band(s) at any given instant in time for detection of moving targets, especially in the littorals. Additionally, the use of its full bandwidth on a single shot basis can provide one of the best ways to detect a stationary, bottomed or hovering target.

The single beam input is the detailed return signal from a hydrophone or hydrophone array. A bank 10 of band pass filters divides the broadband 50–600 Hz return signal into separated 50 Hz bands, the center frequencies of which are given in each of the eleven filters shown in Figure 9. Separate matched filters 12 provide a matched processor. While an analog processor is shown the processors may be digital processors of the type typically used for sonar matched filter detection.

Another detector 14 selects the strongest non-zero target velocity outputs from the processor 14. This automatically seeks 50 Hz band(s) yielding simultaneously the best joint combination of target and propagation response.

A range and azimuth detector 16 of the type conventionally used processes three optimum outputs over a threshold strength to detect azimuth range. A type of combination of outputs and resulting azimuth and range is shown in Figure 1.